**Optimal timing of same-admission orthotopic heart transplantation after left ventricular assist device (LVAD) implantation**

**Running Title: OHT timing and characteristics after LVAD placement**

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**Abstract (250 – 300 words)**

**Background -** The optimal timing of same-admission orthotopic heart transplantation (OHT) after the implantation of left ventricular assist devices (LVAD) is unknown. Some have argued that performing OHT early after LVAD placement poses an increased risk of morbidity and mortality to patients.

**Objectives -** In this study, we describe the impact of timing of same-admission OHT after LVAD implantation on in-hospital mortality and post-transplant length of stay.

**Methods -** Using data from the Nationwide Inpatient Sample (NIS) from 1998 to 2011, we identified patients 18 years of age or older who underwent implantation of a LVAD and for whom the procedure date was available. We calculated in-hospital mortality for those patients who underwent OHT during the same hospitalization as a function of time from LVAD to OHT, adjusting for age, sex, race, household income, and number of comorbid diagnoses. Finally, we analyzed the effect of time to OHT after LVAD implantation on the length of hospital stay post-transplant.

**Results** - 2200 patients underwent implantation of a LVAD in this cohort. 164 (7.5%) patients also underwent OHT during the same hospitalization, which occurred on average 32 days (IQR 7.75 - 66 days) after LVAD implantation. Of patients who underwent OHT, patients who underwent transplantation within 7 days of LVAD implantation (‘early’) experienced increased in-hospital mortality (26.8% vs. 12.2%, p = 0.0483) compared to patients who underwent transplant after 8 days (‘late’). There was no statistically significant difference in age, sex, race, household income, or number of comorbid diagnoses between the early and late groups. Post-transplant length of stay after LVAD implantation was also not significantly different between patients who underwent early versus late OHT.

**Conclusions** - In this cohort of patients who received LVADs, the rate of in-hospital mortality after OHT was lower for patients who underwent late OHT (at least 8 days after LVAD implantation) compared to patients who underwent early OHT. Delayed timing of OHT after LVAD implantation did not correlate with longer hospital stays post-transplant.

**Key Words –** Mechanical Circulatory Support, Orthotopic Heart Transplant, Bridge to Transplant Left Ventricular Assist Device Outcomes

**Abbreviations** – LVAD - Left Ventricular Assist Device

OHT - Orthotopic Heart Transplant

**Introduction**

Heart failure (HF) affects an estimated 5.8 million people in the United States and contributes to over 300,000 deaths every year1,2. It is the most common cause of hospital admission and readmission in people greater than 65 years of age, annually accounting for over 2.4 million hospitalizations2,3 and $39 billion in healthcare costs1,4. Although most patients respond favorably to standard medical treatment, a considerable number of patients progress to end-stage heart failure refractory to medical therapy5. Currently, orthotopic heart transplant (OHT) is the gold standard therapy for these patients6-8, but the number of donor hearts available for transplantation is far fewer than the number of patients on the transplant list. For this reason, left ventricular assist devices (LVADs), a class of electromechanical devices for cardiac circulatory support, are increasingly being used to bridge patients to cardiac transplantation5.  
 The REMATCH trial in 2001 showed significant mortality reductions in patients placed on a pulsatile-flow LVAD compared to standard medical treatment9. Several subsequent studies since have confirmed the survival benefit of both the older pulsatile and newer continuous-flow LVADs10-13. Although LVADs have substantially reduced mortality in end-stage heart failure patients, the absolute mortality rates still remain high. A large portion of this mortality is attributable to complications and other occurrences during the patient’s stay in the hospital15. In-hospital mortality rates as high as 27% have been reported in patients after LVAD surgery15. As the rate of LVAD implantation in the United States continues to increase19-22, effective recommendations on the in-hospital management of LVAD implantation are needed. For example, patients bridged to OHT with a LVAD achieve similar survival rates as patients who undergo direct heart transplant14, but there is little data to guide clinicians on the optimal timing of OHT after LVAD implantation. Some have argued that performing OHT early after LVAD placement poses an increased risk of morbidity and mortality to patients.

Past studies on the appropriate use and outcomes of LVADs have been mostly limited to institutional experience and case series of select populations. While such descriptive investigations are useful, they are often limited by small sample size and variation between institutions and comparison groups. We used the National Inpatient Sample, the largest national database of hospitalizations in the United States with data from over 36 million hospitalizations, to assess the optimal timing of OHT after LVAD implantation. The NIS dataset complements the UNOS database and INTERMACS dataset with additional information on patient comorbidities, additional same-hospitalization procedures, hospital and center characteristics, and markers of patient’s socioeconomic status including insurance provider and regional income quartiles. We analyzed a patient cohort who had OHT performed during the same admission after LVAD implantation. We hypothesized that early OHT after LVAD implantation would be associated with higher mortality than late OHT, and that the hospital length of stay (LOS) after early OHT would be less than LOS after late OHT.

**Methods**

**Data Source**

The Nationwide Inpatient Sample (NIS) from the Healthcare Cost and Utilization Project sponsored by the Agency for Healthcare Research and Quality is the largest database of all-payer inpatient discharge information, sampling approximately 20% of all non-federal US hospitals and including approximately 9 million hospital admissions each year. It contains discharge data from over 5,000 hospitals located across 45 states, of which approximately 1,200 hospitals are sampled each year to create a stratified sample of US hospitals. Each NIS entry includes all diagnosis and procedure codes of activity during the patient’s hospitalization at the time of discharge, as well as patient demographics, hospital characteristics, and short-term complications of the hospitalization.

**Study design and Cohorts**

This was a retrospective cross-sectional study using the Nationwide Inpatient Sample (NIS) between 1998 and 2011. We identified all hospitalizations from 1998 to 2011 of patients 18 years of age or older who underwent LVAD implantation and for whom the hospital day of each procedure was available. Procedures during the hospitalization in addition to LVAD placement, including orthotopic heart transplant, extracorporeal membrane oxygenation, intubation, hemodialysis, invasive hemodynamic monitoring, and surgical revision were identified by associated ICD9 codes (Supplementary Table 1). Additionally, hospital mortality and perioperative morbidity such as post-operative infections, cardiopulmonary complications, and hemorrhagic complications requiring endoscopy were identified.

**Statistical Analysis**

Python 2.7 (Python Software Foundation, www.python.org) and R 2.13 (R Foundation, www.r-project.org) were used for statistical analysis. P-values for numerical and count data were calculated by two-sided t-tests and Chi-squared tests, respectively, with significance thresholds of 0.05. The multivariate linear model evaluating post-LVAD OHT mortality was performed using a generalized linear model with input variable selection by Bayesian Information Criteria (BIC). Dependent variable was in-hospital mortality. Independent variables of age, gender, median income, race, number of comorbidities, LVAD era, and timing of OHT were evaluated in the model.

**Results**

**Baseline Patient Characteristics**

We identified 2200 patients greater than 18 years of age between 1998 and 2011 who underwent LVAD implantation and for whom hospital day of procedure was listed (66.4% of all LVAD patients in NIS database 1998-2011). Comparison of baseline characteristics between this study sample and all LVAD patients in the NIS 1998-2011 database confirmed that our study sample is representative of the entire patient population. The two groups were well matched based on age, sex, household income, prevalence of comorbidities, length of stay, and number of comorbidities, however there were more patients without documented race in the overall group (Supplementary Table 2). The mean age of all patients was 53.4 years (SD = 13.7, range = 18-92 years). Baseline patient demographics, patient comorbidities, and hospital characteristics were well matched between LVAD patients with and without same-admission OHT (Table 1). Most LVAD implantations were performed in large (87.8%), urban (99.1%), teaching hospitals (92.4%). The most common comorbidities were diabetes (17.8%), disorders of lipid metabolism (14.1%), hypertension (13.7%), history of or current use of tobacco (6.5%), and BMI ≥ 30 kg/m2 (4.4%). The mean day of LVAD implantation was 9.4 days (SD = 12.5 days) into the hospitalization. The overall in-hospital mortality rate was 26.8%, with respiratory failure, cardiac dysrhythmias, right heart failure, and renal failure among the most frequent in-hospital complications immediately following LVAD implantation (Table 3).

Our dataset includes patients from both the pulsatile-flow era (1998 - 2005) and the continuous-flow era (2006 - 2011) of mechanical support (Table 2). Comparing the two eras, there was significantly less mortality in the continuous-flow era compared to the pulsatile-flow era (20.4% vs. 43.0%; p < 0.001) even as patients were older (55.4 years vs. 53.2 years; p < 0.001) and suffering more comorbid diagnoses (13.5 vs. 10.6; p < 0.001). During the continuous-flow era, fewer patients received OHT during the same hospitalization as LVAD implantation (3.8% vs. 17.3%; p<0.001), and mechanical support was more frequently initiated in large (88.8% vs. 85.1%; p = 0.002), teaching (94.4% vs. 87.1%; p < 0.001) institutions. Median household income quartile and race distribution also were different between the two eras, although there was no difference in gender ratio of patients.

**Timing of Post-LVAD Orthotopic Heart Transplant**

Of the patients who underwent LVAD implantation, 164 (7.5%) also underwent orthotopic heart transplant (OHT) during the same hospitalization. OHT occurred a median of 32 days (IQR 7.75 - 66 days) after LVAD implantation. Patients who underwent OHT at least 8 days after LVAD implantation experienced significantly lower mortality compared to patients who underwent OHT earlier (26.8% vs. 12.2%; p = 0.048; Table 1 and Figure 1). Baseline patient demographics, patient comorbidities, and hospital characteristics were similar between the early and late OHT groups. LVAD patients who underwent late OHT also had lower mortality compared to LVAD patients who were not transplanted (12.2% vs. 27.0%; p < 0.001). However, LVAD patients who underwent early transplant did not experience a similar mortality benefit (26.8% vs. 27.0%; p = 0.946). Multivariate linear model also confirms the strong association between early OHT after LVAD and in-hospital mortality, independent of patient age, LVAD era, comorbidities, and demographics (Table 4).

Comparing the quartiles of post-LVAD OHT transplant times, there was no statistically significant difference in post-OHT length of stay (23.8 ± 21.4 days for the first quartile, 21.7 ± 15.8 days for the second quartile, 27.6 ± 37.1 days for the third quartile, 27.1 ± 22.8 days for the fourth quartile; p = 0.6571 comparing first quartile to other quartiles; Table 1). However, as expected, patients who waited longer after LVAD implantation for OHT had longer overall hospital stays (39.3 ± 33.2 days for the first quartile, 48.87 ± 25.6 days for the second quartile, 85.8 ± 40.1 days for the third quartile, 151.2 ± 52.6 days for the fourth quartile; p < 0.001 comparing first quartile to other quartiles; Table 1).

**Discussion:**

Our study addresses the difficult question of timing of same-admission OHT after LVAD implantation. Using the inpatient data on procedure timing from the NIS 1998-2011, we show that mortality risk significantly decreases in patients who undergo OHT at least 8 days after LVAD implantation. We also report that post-transplant length of stay is independent of the timing of OHT after LVAD.

For patients who receive an LVAD for bridge to transplant therapy (BTT), the optimal timing of post-LVAD OHT is controversial. The need for clinical stability and time to recover from major surgery is counterbalanced by the risk of LVAD complications and the formation of adhesions and scarring, particularly when OHT is considered early after LVAD implantation. The high failure rate of the early, pulsatile LVADs had in part led to the initial 1999 UNOS allocation algorithm giving LVAD patients 30 days of IA status on the transplant list. The elective nature of the 30 day IA status allows for optimization of management prior to transplant and suggests immediately post-mechanical support is often not the optimal time for transplant. Our data showing that delaying post-LVAD transplant can lead to superior outcomes is consistent with the excellent long term outcomes of BTT mechanical support, pushing some individuals to question the justification of elective IA status23.

Our study confirms previous findings that early transplantation after initiation of BTT mechanical support is associated with worse outcomes with analysis from an underutilized large national database. With procedural timing data of patients who underwent same hospitalization LVAD implantation and transplant, we confirm increased mortality risk associated with early same-admission transplant after LVAD. John et al. (2010)24 have shown that cardiac transplants done less than 6 weeks after LVAD confer higher mortality risk in patients, and Gammie et al. (2003)25 and Ashton et al. (1996)26 have similarly reported optimal timing to be after 2 weeks of LVAD implantation.

During the study period of between 1998 and 2011, there was a significant increase in the number of LVAD implantations, but patient characteristics of this population - including timing of LVAD, usage of invasive hemodynamic monitoring, and timing of post-LVAD OHT - has remained relatively unchanged. Our sample patient population is representative of LVAD patients studied in other databases with regards to age, gender, race, and other demographic characteristics and also mortality trends between the pulsatile and continuous-flow eras. Without randomized control trials to better characterize the optimal management and timing of transplant after LVAD, our study describes representative clinical practice and trends in outcomes associated with changing practice patterns. Our study has a few limitations. First, the NIS is a deidentified administrative database dependent on the appropriate coding of individual ICD-9-CM codes. Studies using such databases are susceptible to errors related to coding such as undercoding complications or variation in the application of diagnostic codes. This database also lacks many details available in registries and unmeasured confounders cannot be excluded. Additionally, the NIS only captures events during the hospitalization, so complications and adverse events after discharge are not recorded. This limitation is counterbalanced by the larger sample size and the absence of reporting bias introduced by the publication of institutional experiences from a few specialized centers. Additionally, patients who underwent LVAD implantation have long hospital stays that capture most, if not all, of the acute complications causing morbidity and mortality. Studies have shown excellent long-term outcomes in LVAD patients who have uncomplicated hospital courses past 30 days.

It is important to note that our cohort only assessed outcomes of OHT after LVAD placement in hospitalized patients. This represents a minority of patients in contemporary practice, as most institutions prefer to wait 2-3 months after LVAD implantation to list patients for cardiac transplantation. Nevertheless, there will continue to be patients in the future who receive same-admission OHT after LVAD implantation, and our study provides meaningful guidelines on the timing of such OHT.

In conclusion, our analysis demonstrates that early same-admission OHT after LVAD implantation is associated with increased mortality. This new understanding of the optimal timing of same-admission OHT after LVAD implantation can greatly improve patient outcomes, although prospective data will be needed to enhance the validity of our findings.

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**Perspectives:**

Competency in System-Based Practice: A multi-disciplinary team of cardiologists, cardiac surgeons, and other medical professionals work together to identify the benefits of various treatments of end stage heart failure.

Translational Outlook 1: The optimal timing for OHT after LVAD remains controversial. This study suggests that OHT soon after LVAD placement (less than 8 days) is associated with more in-hospital mortality. Depending on the clinical scenario, it might be reasonable to defer OHT immediately after LVAD placement.

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# MAIN FIGURES AND TABLES

**Figure 1.** Percent in-hospital mortality by quartiles of wait time for OHT after LVAD implantation and no OHT after LVAD implantation. Percent mortality for each quartile was calculated as number of deaths per quartile by total number of patients per quartile. LVAD, Left Ventricular Assist Device

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| --- | --- | --- | --- | --- | --- |
| Table 1. Baseline demographics for patients who waited 0-7 days, 8-31 days, 32-65 days, and ≥66 days for an Orthotopic Heart Transplant (OHT) after Left Ventricular Assist Device (LVAD) implantation | | | | | |
|  | **0-7 days (n = 41)** | **8-31 days (n = 38)** | **32-65 days (n = 42)** | **≥66 days  (n = 43)** | **No OHT**  **(n = 2036)** |
| Length of stay, mean ± SD | 39.3 ± 33.2 | 48.9 ± 25.6 | 85.8 ± 40.1 | 151.2 ± 52.6 | 37.1 ± 34.6 |
| Length of stay after OHT, mean ± SD | 23.8 ± 21.4 | 21.7 ± 15.8 | 27.6 ± 37.1 | 27.1 ± 22.8 | NA |
| Mortality, n (%) | 11 (26.8) | 5 (13.2) | 5 (11.9) | 5 (11.6) | 564 (27.3) |
| Age, mean ± SD | 50.6 ± 12.6 | 48.6 ± 12.7 | 47.4 ± 15.3 | 46.3 ± 13.1 | 55.4 ± 13.2 |
| Sex, n (%) | | | | | |
| Male | 33 (80.5) | 32 (84.2) | 35 (83.3) | 34 (79.1) | 1525 (74.9) |
| Female | 8 (19.5) | 6 (15.8) | 7 (16.7) | 9 (20.9) | 511 (25.1) |
| Race, n (%) | | | | | |
| White | 25 (61.0) | 19 (50.0) | 23 (54.8) | 22 (51.2) | 1185 (58.2) |
| Black | 3 (7.3) | 5 (13.2) | 8 (19.0) | 6 (14.0) | 330 (16.2) |
| Hispanic | 3 (7.3) | 7 (18.4) | 2 (4.8) | 5 (11.6) | 125 (6.1) |
| Asian/Pacific Islander | 2 (4.9) | 0 (0.0) | 1 (2.4) | 4 (9.3) | 44 (2.2) |
| Native American | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 5 (0.2) |
| Other or unknown | 8 (19.5) | 7 (18.4) | 8 (19.0) | 6 (14.0) | 347 (17.0) |
| Median household income, n (%) | | | | | |
| $1-24,999 | 4 (9.8) | 8 (21.1) | 8 (19.0) | 8 (18.6) | 447 (22.0) |
| $25,000-34,999 | 10 (24.4) | 10 (26.3) | 10 (23.8) | 7 (16.3) | 454 (22.3) |
| $35,000-44,999 | 12 (29.3) | 8 (21.1) | 10 (23.8) | 13 (30.2) | 509 (25.0) |
| $45,000 or more | 12 9 (29.3) | 12 (31.6) | 14 (33.3) | 14 (32.6) | 579 (28.4) |
| Unknown | 3 (7.3) | 0 (0.0) | 0 (0.0) | 1 (2.3) | 47 (2.3) |
| Comorbidities | | | | | |
| Diabetes | 8 (19.5) | 5 (13.2) | 4 (9.5) | 2 (4.7) | 373 (18.3) |
| Hyperlipidemia | 5 (12.2) | 2 (5.3) | 3 (7.1) | 3 (7.0) | 297 (14.6) |
| Hypertension | 5 (12.2) | 1 (2.6) | 2 (4.8) | 2 (4.7) | 291 (14.3) |
| History of smoking | 5 (12.2) | 2 (5.3) | 0 (0.0) | 0 (0.0) | 137 (6.7) |
| BMI ≥ 30 kg/m2 | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 96 (4.7) |
| Number of comorbid diagnoses, mean ± SD | 11.9 ± 3.1 | 12.3 ± 3.0 | 12.5 ± 3.2 | 12.5 ± 3.2 | 12.8 ± 2.9 |
| Location of hospital, n (%) | | | | | |
| Rural | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 17 (0.8) |
| Urban | 41 (100.0) | 38 (100.0) | 42 (100.0) | 43 (100.0) | 2017 (99.1) |
| Unknown | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 2 (0.1) |
| Size of hospital, n (%) | | | | | |
| Small | 4 (9.8) | 0 (0.0) | 0 (0.0) | 2 (4.7) | 32 (1.6) |
| Medium | 7 (17.0) | 6 (15.8) | 5 (11.9) | 0 (0.0) | 211 (10.4) |
| Large | 30 (73.2) | 32 (84.2) | 37 (88.1) | 41 (95.3) | 1791 (88.0) |
| Unknown | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 2 (0.1) |
| Teaching status of hospital, n (%) | | | | | |
| Nonteaching | 1 (2.4) | 1 (2.6) | 2 (4.8) | 1 (2.3) | 160 (7.9) |
| Teaching | 40 (97.6) | 37 (97.4) | 40 (95.2) | 42 (97.7) | 1874 (92.0) |
| Unknown | 0 (0.0) | 0 (0.0) | 0 (0.0) | 0 (0.0) | 2 (0.1) |

SD, Standard Deviation; BMI, Body Mass Index; LVAD, Left Ventricular Assist Device; OHT, Orthotopic Heart Transplant

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| Table 2. Baseline demographics of all LVAD patients, LVAD patients from 1998-2005, and LVAD patients from 2006-2011. | | | | |
|  | **All LVADs (n = 2200)** | **1998-2005 (n = 589)** | **2006-2011 (n = 1611)** | **p-valuea** |
| Mortality, n (%) | 590 (26.5) | 253 (43.0) | 329 (20.4) | <0.001 |
| Same admission OHT, n (%) | 164 (7.5) | 102 (17.3) | 62 (3.8) | <0.001 |
| Length of stay, mean ± SD | 40.5 ± 38.9 | 44.7 ± 48.6 | 39.0 ± 34.6 | 0.008 |
| Age, mean ± SD | 53.4 ± 13.7 | 53.2 ± 13.4 | 55.4 ± 13.4 | <0.001 |
| Sex, n (%) | | | |  |
| Male | 1659 (75.4) | 433 (73.5) | 1226 (76.1) | 0.23 |
| Female | 541 (24.6) | 156 (26.5) | 385 (23.9) |  |
| Race, n (%) | | | | <0.001 |
| White | 1274 (57.9) | 327 (55.5) | 947 (58.8) |  |
| Black | 352 (16.0) | 62 (10.5) | 290 (18.0) |  |
| Hispanic | 142 (6.5) | 28 (4.8) | 114 (7.1) |  |
| Asian/Pacific Islander | 51 (2.3) | 13 (2.2) | 38 (2.4) |  |
| Native American | 5 (0.2) | 1 (0.2) | 4 (0.2) |  |
| Other or unknown | 376 (17.1) | 143 (24.3) | 148 (9.2) |  |
| Median household income, n (%) | | | | <0.001 |
| $1-24,999 | 475 (21.6) | 88 (14.9) | 387 (24.0) |  |
| $25,000-34,999 | 491 (22.3) | 126 (21.4) | 365 (22.7) |  |
| $35,000-44,999 | 552 (25.1) | 141 (23.9) | 411 (25.5) |  |
| $45,000 or more | 631 (28.7) | 214 (36.3) | 417 (25.9) |  |
| Unknown | 51 (2.3) | 20 (3.4) | 31 (2.4) |  |
| Comorbidities | | | |  |
| Diabetes | 391 (17.8) | 91 (15.4) | 300 (18.6) | 0.097 |
| Hyperlipidemia | 310 (14.1) | 61 (10.4) | 249 (15.5) | 0.003 |
| Hypertension | 309 (14.0) | 88 (14.9) | 221 (13.7) | 0.508 |
| History of smoking | 131 (6.0) | 29 (4.9) | 102 (6.3) | 0.257 |
| BMI ≥ 30 kg/m2 | 96 (4.4) | 12 (2.0) | 84 (5.2) | 0.002 |
| Number of comorbid diagnosis, mean ± SD | 12.7 ± 2.9 | 10.6 ± 2.9 | 13.5 ± 2.5 | <0.001 |
| Location of hospital, n (%) | | | | 0.73 |
| Rural | 17 (0.8) | 5 (0.8) | 12 (0.7) |  |
| Urban | 2181 (99.1) | 583 (99.0) | 1598 (99.2) |  |
| Unknown | 2 (0.1) | 1 (0.2) | 1 (0.1) |  |
| Size of hospital, n (%) | | | | 0.002 |
| Small | 38 (1.7) | 20 (3.4) | 18 (1.1) |  |
| Medium | 229 (10.4) | 67 (11.4) | 162 (10.1) |  |
| Large | 1931 (87.8) | 501 (85.1) | 1430 (88.8) |  |
| Unknown | 2 (0.1) | 1 (0.2) | 1 (0.1) |  |
| Teaching status of hospital, n (%) | | | | <0.001 |
| Nonteaching | 165 (7.5) | 75 (12.7) | 90 (5.6) |  |
| Teaching | 2033 (92.4) | 513 (87.1) | 1520 (94.4) |  |
| Unknown | 2 (0.1) | 1 (0.2) | 1 (0.1) |  |

aPairwise t-test or chi-square test for patients before 2006 and patients 2006 and afterwards.

SD, Standard Deviation; BMI, Body Mass Index; LVAD, Left Ventricular Assist Device; OHT, Orthotopic Heart Transplant

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| Table 3. Complications in hospitalized patients with or without same admission Orthotopic Heart Transplant (OHT) after Left Ventricular Assist Device (LVAD) | | | | |
|  | **Early OHT (n = 41)** | **Late OHT (n = 123)** | **OHT- (n = 2036)** | **Total (n = 2200)** |
| Acute renal failure | 24 (58.5) | 64 (52.0) | 963 (47.3) | 1051 (47.8) |
| Reoperation | 28 (68.3) | 87 (70.7) | 803 (39.4) | 918 (41.7) |
| Bleeding requiring transfusion | 7 (17.1) | 30 (24.4) | 780 (38.3) | 817 (37.1) |
| Acute respiratory failure | 8 (19.5) | 37 (30.1) | 518 (25.4) | 563 (25.6) |
| Sepsis | 2 (4.9) | 17 (13.8) | 233 (11.4) | 252 (11.5) |
| Postoperative cardiac complication | 7 (17.1) | 15 (12.2) | 234 (11.5) | 256 (11.6) |
| Acute liver failure | 3 (7.3) | 9 (7.3) | 224 (11.0) | 236 (10.7) |
| Device failure | 0 (0.0) | 4 (3.3) | 62 (3.0) | 66 (3.0) |
| Stroke | 1 (2.4) | 1 (0.8) | 53 (2.6) | 55 (2.5) |

\*All pairwise comparisons of early vs. late OHT were not statistically significant (p > 0.05).

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| Table 4. A generalized multivariate linear model to evaluate post-LVAD OHT mortality. Positive estimates reflect positive association with increased mortality. | | | |
|  | **Regression coefficient** | **Standard Error** | **p-value** |
| Age | 0.003 | 0.002 | 0.158 |
| Female sex | 0.071 | 0.075 | 0.342 |
| Caucasian race | -0.010 | 0.027 | 0.695 |
| Median household income | 0.013 | 0.027 | 0.638 |
| Number of comorbidities | 0.006 | 0.010 | 0.518 |
| Years 1998-2005 | 0.096 | 0.060 | 0.113 |
| Early OHT | 0.200 | 0.067 | 0.004\* |

\*p-value < 0.05

# SUPPLEMENTARY TABLES

|  |  |
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| Supplementary Table 1. ICD9 codes of diagnosis and procedures | |
| Diagnosis/Procedure | **ICD9 Code(s)** |
| Left ventricular assist device | 3766 |
| Orthotopic heart transplant | 3751, 375 |
| Swan-Ganz catheterization | 8964 |
| Diabetes | 25000-25099 |
| Disorders of lipoid metabolism | 2720-2729 |
| Hypertension | 4010-4019 |
| History of or current use of tobacco | V1582, 3051 |
| BMI ≥ 30 kg/m2 | 27800, 27801 |
| Reoperation | 3403, 3764, 3479, 341, 3749 |
| Sepsis | 99591, 99592 |
| Acute respiratory failure | 51881 |
| Postoperative cardiac complication | 9971, 4294 |
| Acute renal failure | 5845-5849 |
| Postoperative bleeding | 4513, 4523, 9904, 9905, 9907, 9909 |
| Stroke | 43491 |
| Acute liver failure | 570 |
| Device failure | 99609 |

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| Supplementary Table 2. Baseline demographics between LVADs from our sample dataset and all adult (≥ 18 years old) LVADs in the National Inpatient Sample (NIS) | | | |
|  | **Sample LVADs (n = 2200)** | **Total NIS LVADs (n = 3219)** | **p-value** |
| Mortality, n (%) | 590 (26.5) | 564(27.0) | 0.968 |
| Same admission OHT, n (%) | 164 (7.5) | 267 (8.3) | 0.241 |
| Length of stay, mean ± SD | 40.5 ± 38.9 | 41.2 ± 40.2 | 0.548 |
| Age, mean ± SD | 53.4 ± 13.7 | 54.5 ± 13.3 | 0.412 |
| Sex, n (%) | | | 0.691 |
| Male | 1659 (75.4) | 2434 (75.9) |  |
| Female | 541 (24.6) | 772 (24.1) |  |
| Race, n (%) | | | <0.001 |
| White | 1274 (57.9) | 1742 (54.3) |  |
| Black | 352 (16.0) | 444 (13.9) |  |
| Hispanic | 142 (6.5) | 169 (5.3) |  |
| Asian/Pacific Islander | 51 (2.3) | 57 (1.8) |  |
| Native American | 5 (0.2) | 11 (0.3) |  |
| Other or unknown | 376 (17.1) | 783 (24.4) |  |
| Median household income, n (%) | | | 0.571 |
| $1-24,999 | 475 (21.6) | 637 (19.9) |  |
| $25,000-34,999 | 491 (22.3) | 738 (23.1) |  |
| $35,000-44,999 | 552 (25.1) | 832 (25.8) |  |
| $45,000 or more | 631 (28.7) | 932 (29.1) |  |
| Unknown | 51 (2.3) | 67 (2.1) |  |
| Comorbidities | | |  |
| Diabetes | 392 (17.8) | 535 (16.6) | 0.266 |
| Hyperlipidemia | 310 (14.1) | 420 (13.0) | 0.287 |
| Hypertension | 301 (13.7) | 418 (13.0) | 0.483 |
| History of smoking | 144 (6.5) | 201 (6.2) | 0.697 |
| BMI ≥ 30 kg/m2 | 96 (4.4) | 130 (4.0) | 0.604 |
| Number of comorbid diagnosis, mean ± SD | 12.7 ± 2.9 | 12.4 ± 3.0 | 0.945 |

SD, Standard Deviation; BMI, Body Mass Index; LVAD, Left Ventricular Assist Device; OHT, Orthotopic Heart Transplant

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| Supplementary Table 3. Baseline demographics of all LVAD patients, LVAD patients who underwent OHT, and LVAD patients who did not undergo OHT | | | |
|  | **All LVADs (n = 2200)** | **OHT- (n = 2036)** | **OHT+  (n = 164)** |
| Mortality, n (%) | 590 (26.5) | 564 (27.3) | 26 (15.9) |
| Length of stay, mean ± SD | 40.5 ± 38.9 | 37.1 ± 34.6 | 82.8 ± 59.3 |
| Age, mean ± SD | 53.4 ± 13.7 | 55.4 ± 13.2 | 48.2 ± 13.5 |
| Sex, n (%) | | | |
| Male | 1659 (75.4) | 1525 (74.9) | 134 (81.7) |
| Female | 541 (24.6) | 511 (25.1) | 30 (18.3) |
| Race, n (%) | | | |
| White | 1274 (57.9) | 1185 (58.2) | 89 (54.3) |
| Black | 352 (16.0) | 330 (16.2) | 22 (13.4) |
| Hispanic | 142 (6.5) | 125 (6.1) | 17 (10.4) |
| Asian/Pacific Islander | 51 (2.3) | 44 (2.2) | 7 (4.3) |
| Native American | 5 (0.2) | 5 (0.2) | 0 (0.0) |
| Other or unknown | 376 (17.1) | 347 (17.0) | 29 (17.7) |
| Median household income, n (%) | | | |
| $1-24,999 | 475 (21.6) | 447 (22.0) | 28 (17.1) |
| $25,000-34,999 | 491 (22.3) | 454 (22.3) | 37 (22.6) |
| $35,000-44,999 | 552 (25.1) | 509 (25.0) | 43 (26.2) |
| $45,000 or more | 631 (28.7) | 579 (28.4) | 52 (31.7) |
| Unknown | 51 (2.3) | 47 (2.3) | 4 (2.4) |
| Comorbidities | | | |
| Diabetes | 392 (17.8) | 373 (18.3) | 19 (11.6) |
| Hyperlipidemia | 310 (14.1) | 297 (14.6) | 13 (7.9) |
| Hypertension | 301 (13.7) | 291 (14.3) | 10 (6.1) |
| History of smoking | 144 (6.5) | 137 (6.7) | 7 (4.3) |
| BMI ≥ 30 kg/m2 | 96 (4.4) | 96 (4.7) | 0 (0.0) |
| Number of comorbid diagnosis, mean ± SD | 12.7 ± 2.9 | 12.8 ± 2.9 | 12.3 ± 3.1 |
| Location of hospital, n (%) | | | |
| Rural | 17 (0.8) | 17 (0.8) | 0 (0.0) |
| Urban | 2181 (99.1) | 2017 (99.1) | 164 (100.0) |
| Unknown | 2 (0.1) | 2 (0.1) | 0 (0.0) |
| Size of hospital, n (%) | | | |
| Small | 38 (1.7) | 32 (1.6) | 6 (3.7) |
| Medium | 229 (10.4) | 211 (10.4) | 18 (11.0) |
| Large | 1931 (87.8) | 1791 (88.0) | 140 (85.4) |
| Unknown | 2 (0.1) | 2 (0.1) | 0 (0.0) |
| Teaching status of hospital, n (%) | | | |
| Nonteaching | 165 (7.5) | 160 (7.9) | 5 (3.0) |
| Teaching | 2033 (92.4) | 1874 (92.0) | 159 (97.0) |
| Unknown | 2 (0.1) | 2 (0.1) | 0 (0.0) |

SD, Standard Deviation; BMI, Body Mass Index; LVAD, Left Ventricular Assist Device; OHT, Orthotopic Heart Transplant